



METHOD FOR IMPROVING THE IMAGING PROPERTIES OF AT LEAST TWO  
OPTICAL ELEMENTS AND PHOTOLITHOGRAPHIC FABRICATION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of International  
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5 BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method for improving the imaging  
properties of at least two optical elements. More  
particularly, the invention relates to such a method in  
which the relative position of the optical elements is  
10 mutually adjusted in order to improve the optical imaging.  
The invention further relates to a photolithographic  
fabrication method.

2. Description of Related Art

From EP 1 063 684 A1 it is known to determine the  
15 birefringence distribution of individual lenses inside a  
projection lens of a projection exposure system as a  
polarisation-dependent perturbation. The lenses are then  
selected and arranged inside the projection lens so as to  
obtain a total birefringence whose magnitude is less than a

predetermined limit value for each optical path through the projection lens. The total birefringence is in this case made up of the sum of all the birefringences of the individual lenses being analysed. Such a method is helpful  
5 when lenses need to be rejected on the basis of an intolerable birefringence distribution, but in practice does not always lead to specification values being achieved for the imaging properties of the optical elements.

Another optimisation method is known from the specialist  
10 article "The development of microlithographic high-performance optics", Int. J. of Optoelec., 1989, 545. When optimising the imaging properties of optical systems having optical elements which are made of crystalline materials, this method provides satisfactory results only if the  
15 crystalline materials are specially selected and the optical elements are mounted without stress. Such measures are expensive.

#### SUMMARY OF THE INVENTION

It is therefore a first object of the present invention to  
20 refine an optimisation method of the type mentioned in the introduction, so that a total imaging error made up of the imaging errors of the individual optical components can be further reduced for most practical applications.

This object is achieved according to the invention by a  
25 method having the features mentioned in Claim 1.

The method according to the invention is based on the following facts:

- As a rule, polarisation-dependent and polarisation-independent perturbations contribute to the total  
5 perturbation. Polarisation-dependent perturbations can be subdivided into: intrinsically present polarisation-dependent perturbations, such as the intrinsic birefringence, i.e. that which occurs even in a homogeneous and stress-free material; polarisation-dependent  
10 perturbations occurring because of external effects, such as stress birefringence; and polarisation-dependent perturbations occurring because of material inhomogeneities, such as birefringence due to crystal defects, especially due to the formation of domains in the material.
- 15 As a rule, previous determination methods for determining the imaging errors of optical elements have been restricted to polarisation-independent perturbations, since it was assumed that conventional optical materials have polarisation-dependent perturbations only in exceptional  
20 cases. These polarisation-dependent perturbations have previously been accommodated without including them in a target-position calculation. This was done, as mentioned above, by material selection or special mounting.

It is known from the Internet publication "Preliminary  
25 determination of an intrinsic birefringence in  $\text{CaF}_2$ " by J. H. Burnett, G. L. Shirley and Z. H. Levine, NIST Gaithersburg MD 20899 USA (posted on 7.5.01), however, that single  $\text{CaF}_2$  crystals also have non-stress-induced, i.e. intrinsic

birefringence. This applies, for example, to ray propagation in the (110) crystal direction. For ray propagation in the (100) crystal direction and in the (111) crystal direction, however,  $\text{CaF}_2$  does not have any intrinsic  
5 birefringence. The birefringence that occurs is therefore dependent on the ray direction. It cannot be eliminated either by material selection or by stress-free mounting of an optical element.

Since  $\text{CaF}_2$  and other crystalline materials with intrinsic  
10 birefringence are being used increasingly as optical materials, particularly in conjunction with UV light sources, the neglect of polarisation-dependent perturbations is leading to imaging errors which are not picked up in the known optimisation methods.

15 Polarisation-dependent perturbations cause light rays with orthogonal polarisations to be imaged at different positions. Polarisation effects can furthermore cause individual polarisation components to experience different imaging errors.

20 Although the aforementioned EP 1 063 684 A1 takes into account a polarisation-dependent perturbation, namely the birefringence, it ignores other perturbations in the scope of optimising the mutual arrangement of the optical components, so that there may some be error contributions  
25 to the total imaging error which are avoidable.

According to the invention, both the polarisation-dependent perturbations and the polarisation-independent

perturbations are taken into account in the target-position calculation. In this way, the optical elements can be modelled precisely and fully in respect of their imaging properties.

- 5 The polarisation-dependent perturbation according to Claim 2 takes into account the effect of internal stresses in the optical materials. These internal stresses may, for instance, have been frozen in the material during the production process, or may occur because of the mechanical  
10 mounting (frame) of the optical element. Taking the stress birefringence into account improves the optimisation of the imaging properties even for optical elements which do not have any intrinsic stress birefringence.

Determining the position of at least one crystal axis  
15 according to Claim 3 can obviate further measurement of polarisation-dependent perturbations in the most favourable case, if there are no other polarisation-dependent perturbations, since the intrinsic birefringence can be calculated following determination of the crystal axis  
20 position.

A degree of freedom in movement which is relatively straightforward to achieve, since it does not involve significant intervention in the mounting of the optical element, is the rotatability of the at least one optical  
25 element according to Claim 4.

The effects of displacing a linearly displaceable optical element according to Claim 5 on the imaging properties of

the at least two optical elements allow precise predictions, for example by means of optical design programs, which facilitates calculation of the target position.

Centring errors, in particular, can be compensated for by a  
5 displaceable optical element according to Claim 6.

A tiltable optical element according to Claim 7, for example, allows alignment of the crystal axes of the optical element relative to the optical axis of an overall optical system, which includes the at least two optical  
10 elements.

The effect of determining the polarisation-dependent perturbation according to Claim 8 is that the contributions to the stress birefringence from the frame are also taken into account in the determination of the polarisation-  
15 dependent perturbation. This increases the precision of the optimisation method.

It is also an object of the present invention to provide a photolithographic fabrication method with improved optical quality.

20 This object is achieved according to the invention by a method having the features mentioned in Claim 9. The advantages of the fabrication method derive from the aforementioned advantages of the optimisation method.

At an exposure wavelength according to Claim 10, many  
25 optical materials have polarisation-dependent perturbations

which affect the imaging properties of optical elements more strongly than, for example, when they are exposed to visible light. The optimisation method according to the invention is therefore very effective with exposure to  
5 wavelengths of less than 200 nm.

#### BRIEF DESCRIPTION OF THE DRAWINGS

An exemplary embodiment of the invention will be explained in more detail below with reference to the drawing, in which:

10 Figure 1 shows a projection exposure system for microlithography;

Figure 2 shows a section through a block of a single crystal as the starting material for a lens of projection lens for the projection exposure system  
15 in Figure 1;

Figure 3 shows a schematic representation of the intrinsic birefringence of an optical plate, made from a single crystal, of the projection lens for the projection exposure system in Figure 1;

20 Figure 4 shows a coordinate system defining an aperture angle and an azimuth angle for rays of a projection light beam of the projection exposure system in Figure 1; and

Figure 5 shows the profile of the intrinsic birefringence of the optical plate in Figure 3 as a function of the azimuth angle.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5 A projection exposure system denoted overall by 1 in Figure 1 is used for transferring a structure from a mask 2 to a wafer (not shown in Figure 1).

A light source 3, for example an F<sub>2</sub> laser with a wavelength of 157 nm, generates a projection light beam 4 for this  
10 purpose. It passes first through illumination optics 5 for shaping, and subsequently through the mask 2. A projection lens 6 images the structure present on the mask 2 onto the wafer.

In Figure 1, the projection lens 6 is divided into a part 7,  
15 rotatable about the optical axis of the projection lens 6, and a stationary part 8. In practice, there are often a plurality of rotatable parts in the projection lens 6; restriction to only one rotatable part 7, however, will suffice for the purpose of this description.

20 In Figure 1, a biconvex lens 9 is indicated to exemplify the optical components of the rotatable part 7 and a plane-parallel optical plate 10 is indicated to exemplify the optical components of the stationary part 8. Furthermore, as illustrated by a Cartesian coordinate system 20 in Fig.  
25 1, the lens 9 is displaceable both along the optical axis and transversely to the optical axis of the projection lens

6, and it is also tiltable relative to the optical axis of the projection optics 6 as indicated by a double arrow 21 in Fig. 1. The double arrow 21 here denotes one of two possible and mutually perpendicular tilting movements  
5 relative to the optical axis. Other optical elements of the projection lens 6, which are not explicitly represented in Fig. 1, may also have the said degrees of freedom in movement.

A position-sensitive sensor 11 is provided in order to  
10 analyse perturbations which affect the imaging properties of the projection lens 6. It is displaceable transversely to the optical axis of the projection lens 6, between a measurement position represented in Figure 1 and a projection exposure position (not shown) withdrawn from the  
15 optical path of the projection light beam 4 (cf. double arrow 12 in Fig. 1). The sensor 11 is connected to a computer 14 via a signal line 13.

The lens 9 and the optical plate 10 are made from single crystals of  $\text{CaF}_2$ , which has a cubic crystal symmetry. For  
20 production, these optical elements 9, 10 are cut from crystal blocks and polished.

Such a crystal block 15 for the lens 9 is represented by way of example in Fig. 2. It is oriented such that (100) crystal planes 16 are perpendicular to the plane of the  
25 drawing, so that their section lines constitute lines extending horizontally with the plane of the drawing. The lens 9 is machined from the crystal block 15 so that its element axis EA, i.e. the optical axis of the lens 9,

coincides with the (100) crystal direction, which is perpendicular to the (100) crystal plane.

The optical plate 10, which is represented separately in Fig. 3, is also machined from a crystal block with such an orientation. Besides the (100) crystal direction, the (101), (110), (10-1) and (1-10) crystal directions are also represented there as arrows, the negative sign when indexing the crystal direction in this description being equivalent to the designation "upper crosswise" in the drawing. An intrinsic birefringence of the optical plate 10 is schematically represented by four "lobes" 17, the areas of which indicate the magnitude of the intrinsic birefringence for the respective ray direction of a light ray of the projection light beam 4 (cf. Figure 1). The maximum intrinsic birefringence of the optical plate 4 is respectively obtained in the (101), (110), (10-1) and (1-10) crystal directions.

The ray direction of a light ray 18 of the projection light beam 4 is defined by an aperture angle  $\theta$  and an azimuth angle  $\alpha$ . Figure 4 illustrates the position of these two angles: a Cartesian coordinate system of the projection exposure system 1 is shown there, the z axis of which coincides with the optical axis of the projection lens 6. The aperture angle  $\theta$  is the angle between the light ray 18 and the z axis. The azimuth angle  $\alpha$  is the angle between the x axis and the projection of the light ray 18 onto the xy plane.

In the following description, the optical components 9, 10 are oriented so that the (100) crystal direction coincides with the z axis and the projection of the (101) crystal direction onto the xy plane coincides with the x axis.

5 Figure 5 shows the intrinsic birefringence (IDB) of the optical plate 10 as a function of the azimuth angle  $\alpha$  for the aperture angle  $\theta = 45$  degrees. A fourfold symmetry is found, the maxima of the intrinsic birefringence being obtained for light rays whose ray directions coincide with  
10 the (101), (110), (10-1) and (1-10) crystal directions (cf. Figure 3), that is to say for light rays with an aperture angle  $\theta$  of 45 degrees and an azimuth angle  $\alpha$  of 0 degrees, 90 degrees, 180 degrees and 270 degrees. The intrinsic birefringence vanishes (cf. Figure 3) at an aperture angle  
15 of 0 degrees, i.e. a ray direction along the optical axis of the projection lens 6 in the (100) crystal direction.

As the maximum intrinsic birefringence (ray propagation e.g. in the (110) crystal direction, i.e.  $\theta$  equal to 45 degrees,  $\alpha$  equal to 90 degrees), a value of  $(11.0 \pm 0.4)$  nm/cm was  
20 measured at a wavelength of 156.1 nm for  $\text{CaF}_2$ .

At the azimuth angles for which intrinsic birefringence occurs (cf. Figure 5), it decreases continuously with the aperture angle for aperture angles of less than 45 degrees (cf. Figure 3).

25 Besides these intrinsic contributions to the birefringence, the lens 9 and the optical plate 10 have additional stress birefringence contributions depending on their installation

situation in the projection lens 6, which are added to the intrinsic birefringence. Further birefringence contributions may, for example, be due to crystal defects, in particular the formation of domains. There may even be non-  
5 intrinsic birefringence contributions in optical materials which do not have any intrinsic birefringence.

A method for improving the imaging properties of the projection lens 6 is carried out as follows:

First, the optical perturbations of all the optical  
10 elements of the projection lens 6 are determined individually. Such measurement methods for determining the aforementioned birefringence contributions as an example of polarisation-dependent perturbations, on the one hand, and polarisation-independent perturbations, on the other hand,  
15 are known to the person skilled in the art. To this end, for example, as indicated by the sensor 11 in Figure 1, a measurement of the overall imaging properties of the projection lens 6 may be carried out in different adjustment states of the projection lens 6.

20 As an alternative or in addition, the individual optical elements of the projection lens 6 may be analysed independently of one another with the aid of known measurement methods. In this case, care should be taken to simulate the installation situation of the optical elements  
25 in the projection lens 6 as precisely as possible during this independent analysis, so as to prevent the installation of the optical elements in the projection exposure system 1 from giving rise to additional

perturbation contributions, which impair the optimisation of the imaging properties of the projection lens 6.

The determination of the birefringence contributions may, for example, comprise determination of the position of the  
5 crystal axes of the optical elements to be analysed, when crystalline materials are involved.

The measurement results are evaluated by the computer 14. It determines the respective perturbation contributions of the individual optical elements of the projection lens, and  
10 assigns these contributions to the individual polarisation-dependent and polarisation-independent perturbations. The computer 14 subsequently calculates and optimises a target function (merit function). This target function takes in the dependencies of the perturbation contributions of all  
15 the optical elements on the degrees of freedom in movement of these optical elements (rotation, inclination, centring).

In the exemplary embodiment which is represented, this calculation is carried out for the optical components 9 and 10.

20 As was mentioned above, the lens 9 is rotatable relative to the optical plate 10 about the optical axis. For the lens 9 and the optical plate 10, their respective contributions to the polarisation-dependent and polarisation-independent perturbations are available after the perturbation  
25 contributions have been analysed. Besides the perturbations of the lens 9 and the optical plate 10, the merit function also contains the dependency of the perturbation

contributions of the lens 9 on its rotation about the optical axis.

- The merit function is subsequently optimised by varying of the degrees of freedom in movement of the mobile parts of the projection lens 6. In the embodiment according to Figure 1, the merit function is evaluated at each rotation position of the rotatable part 7 of the projection lens 6. The rotation position in which the merit function has the optimum value is subsequently determined.
- 10 Finally, the mobile optical elements are brought into the target position which has been determined. In the embodiment according to Figure 1, the rotatable part 7 with the lens 9 is rotated into the target position which has been determined.